Oregon Department of Geology & Mineral Industries
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OLC Canyon Creek 2016 Lidar Project
Lidar QC Report – December 29, 2016

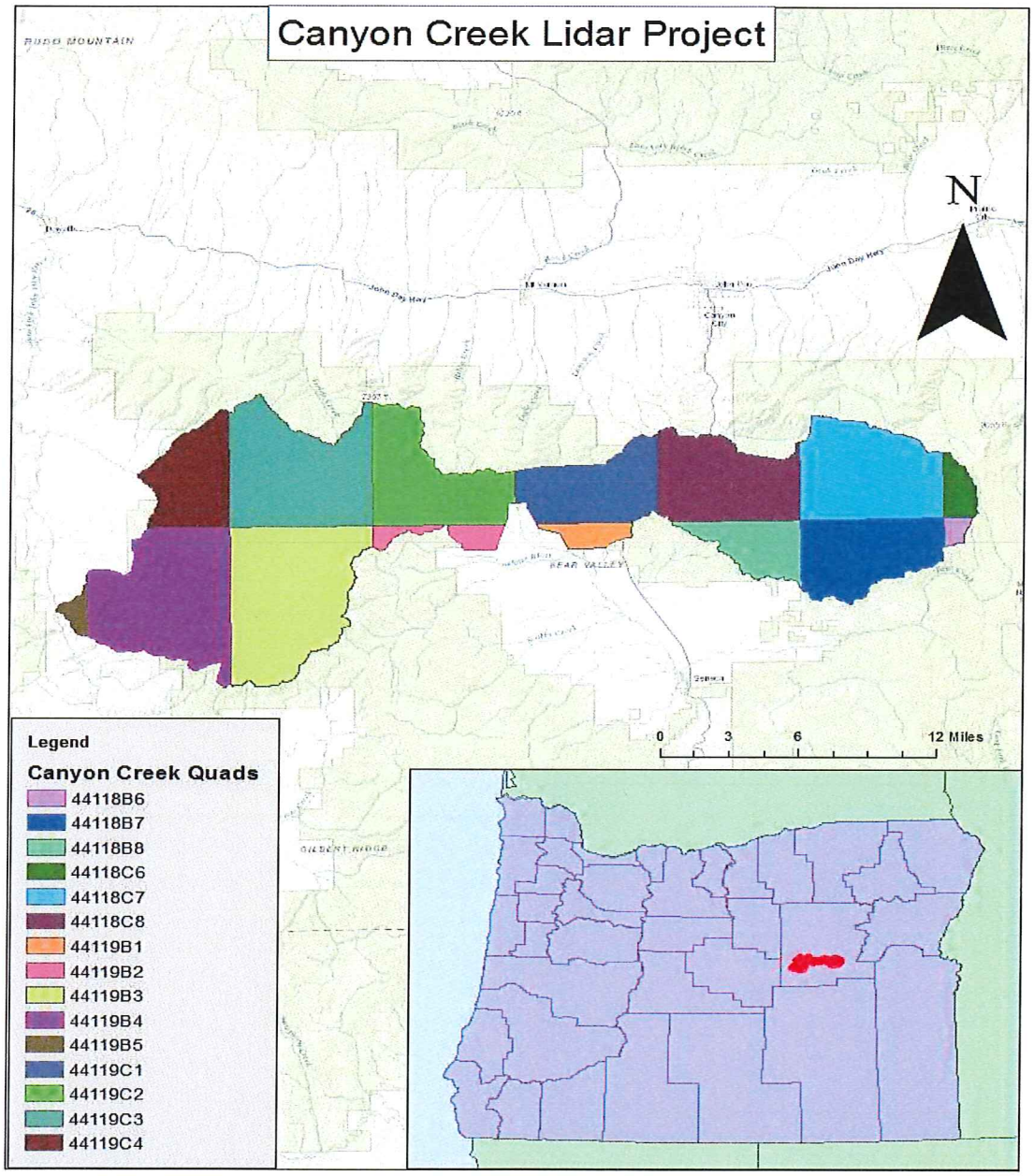

Figure 1. Map featuring the OLC Canyon Creek 2016 project data extent.

The Oregon Department of Geology & Mineral Industries (DOGAMI) has contracted with a vendor, Watershed Sciences, Inc. (WSI) to collect high resolution lidar topographic data for multiple areas within the Pacific Northwest. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C of the 2007-2014 Lidar Data Acquisition Price Agreement (OPA #8865, pages 14-23). Data submitted under this price agreement are to be collected at a resolution of at least 8 pulses per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon the OLC Canyon Creek 2016 lidar project (Figure 1) products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor, all lidar data for OLC Canyon Creek 2016 were independently reviewed by DOGAMI staff to ensure project specifications were met. All data were inventoried for completeness and checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy. The specific quality control checks are:

- Data Completeness examines all data associated with this delivery to ensure that all required data products are present and function correctly. Quality control review is conducted on every data file delivered to DOGAMI. LASer format (LAS) point files have been loaded into TerraSolid™ and ArcGIS™™ to ensure complete and correct lidar data coverage and file integrity. Raster and vector files have been viewed in ArcMap and cross referenced with the delivery area to ensure proper coverage, extent and integrity.
- Spot Diameter Analysis determines the area of ground that is intersected by a laser pulse from the lidar sensor. The spot diameter is a product of the flying height of the aircraft and the beam divergence of the sensor used during acquisition of the data
- Swath-to-Swath Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality. Poor calibration leads to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual Analysis is carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The vendor reviews the automated classification to fix misclassifications of point data. The delivered bare earth digital elevation model (DEM) and highest hit digital surface model (DSM) are then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts If valid errors are found, data must be corrected and resubmitted.
- Absolute Accuracy Analysis compares the delivered bare-earth DEMs with independent Ground Check Points (GCPs) to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI staff collects independent GCPs with survey-grade GPS, which are then compared against delivered lidar elevation models.

- Pulse Density analysis examines the all-return LAS point cloud and parses out first-return laser points based on the header information for each LAS file. First-return LAS points are then compared to the area of the LAS tile boundaries to determine the pulse density within each LAS tile and the average pulse density for the entire project.
- Metadata Analysis compares the structure of the metadata file against FGDC standards. Metadata content is reviewed by using a visual check as well as analysis by the USGS Geospatial Metadata validation service.

Data Completeness

The OLC Canyon Creek 2016 project area was collected between June 7th and June 20th, 2016. The total area of delivered data equals 251.67 square miles (161,068 acres). This delivery contains data for the following 15 USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the OLC Canyon Creek 2016 survey collection area (Figure 2).

Delivery: 44118B6, 44118B7, 44118B8, 44118C6, 44118C7, 44118C8, 44119B1, 44119B2, 44119B3, 44119B4, 44119B5, 44119C1, 44119C2, 44119C3, 44119C4

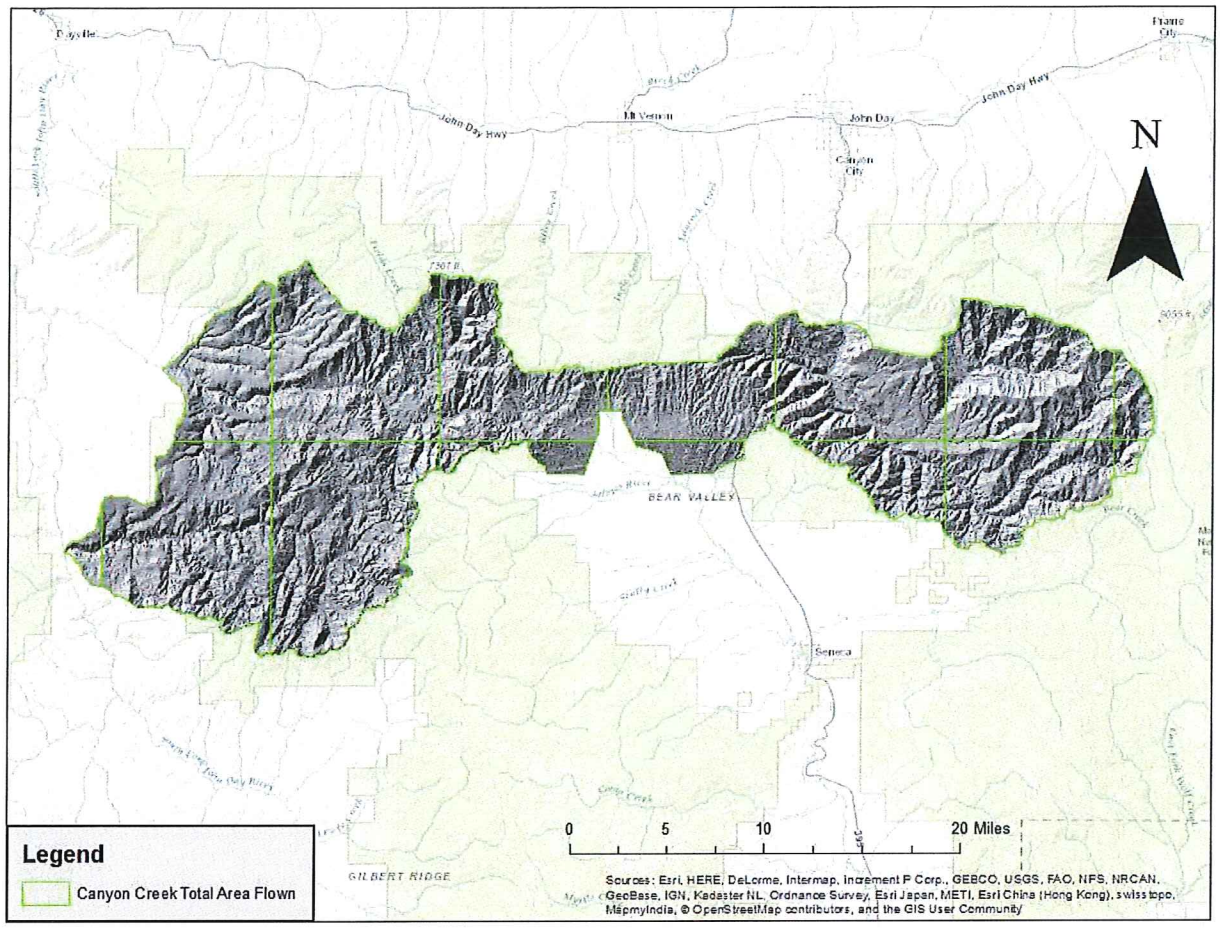

Figure 2. OLC Canyon Creek 2016 collection area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Canyon Creek project.

We review data acquisition parameters to ensure that the vendor has met all data collection requirements outlined in the Lidar Data Acquisition Price Agreement (OPA #8865). DOGAMI staff verifies acquisition specifications by analyzing LAS point data records. Every LAS file (version 1.2 or higher) contains binary data consisting of a header block, variable length record and point data. The header block contains information such as point numbers, coordinate bounds, and GPS time. The variable length record includes information on who created the data and the recorded length of information. The point data records include information on return number, intensity value and scan angle rank. Using the "Create LAS Dataset" tool in the ArcGIS™ Data Management toolbox, we analyze multiple LAS headers and create statistical information about the collection method for the entire project. Analyzing the LAS files and the information stored within them allows DOGAMI to verify acquisition requirements were met during data collection (Table 1).

Quality Control for Aerial Acquisition Specifications			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Survey Conditions	Lidar data collection shall be conducted in snow-free conditions with the contractor make best effort to acquire data in leaf-off and low stream conditions	Yes	None
Pulse Returns	Lidar sensor used must be capable of recording a minimum of 4 returns per laser pulse, including first and last returns.	Yes	5 return classes
Spot Diameter	Produce an on-ground laser spot diameter no less than 15cm and no greater than 40cm	Yes	None
Horizontal Datum	North American Datum (NAD) 83 (2011) or the most current horizontal datum at the beginning of the survey	Yes	None
Vertical Datum	North American Vertical Datum (NAVD) 88 (Geoid 12A) or the most current Geoid model at the beginning of the survey	Yes	None
Scan Angle	Laser scan angle must not exceed 30 degrees overall (+15 to -15 degrees)	Yes	None
Swath Overlap	Contractor shall plan surveys with 50% sidelap of adjacent swaths. Survey must be designed for 100% double coverage at planned aircraft height above ground.	Yes	None
Design Pulse Density	Aggregate design multi-swath pulse density must be 8.0 pulses per square meter or higher.	Yes	None
Intensity Range	Record intensity range of at least 8 bits	Yes	None
GPS Procedures	At least two dual frequency L1-L2 GPS reference receivers operating during missions at 1 Hz or higher. All GPS measurements must be made with Positional Dilution of Precision (PDOP) less than or equal to 3.0 with at least 6 satellites in view.	Yes	None

Table 1. Acquisition Specifications Checklist

We review each product deliverable's format, resolution and tiling scheme in order to verify content completeness. The OLC Canyon Creek 2016 lidar project includes data in the format of LAS point files, bare earth grids, highest hit grids, intensity images, trajectory files, ground point density rasters, RTK survey data, a shapefile of the delivery area and the report of survey. Lidar all-return point cloud data is delivered as LAS binary format with all required attribute fields populated (Table 2). Bare earth surface models are created from identified ground points and interpolated via triangulated irregular network into an ArcGIS™ Grid format with 3ft cell size (Table 3). Highest hit digital elevation models are created from a raster of first-return points that are delivered in ArcGIS™ Grid format with 3ft cell size (Table 4). Georeferenced intensity images created from first-return points and are supplied in TIF format (Table 5). Supplementary data including trajectory files, ground density rasters, real time kinematic ground survey data (used for absolute vertical adjustment) and delivery area shapefiles are provided in various formats (Table 6). The report of survey is a digital text report, supplied by the vendor, that describes lidar data collection methods and processing. The report also provides accuracies associated with calibration, consistency, absolute error and point classification (Table 7).

Quality Control for Delivered All-Return LAS Files			
Specifications	**Description**	**Checked on this delivery**	**Comments**
LAS File Description	Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).	Yes	None
Format	LAS version 1.2 or most commonly distributed LAS format files, as specified in a Purchase Order	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 1983 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Vertical Datum	NAVD 88 (Geoid 12A)	Yes	None
Vertical Units	International Feet	Yes	None
Classification	Class 1 - Unclassified; Class2 – Ground Classification of ground returns must be as complete as is feasible and without avoidable return misclassification	Yes	None
Return Number	Must list all valid returns – Lidar sensor used must be capable of recording a minimum **of 4 returns per laser pulse**, including first and last returns.	Yes	Up to 5 returns were recorded
Time	GPS Seconds per week Use header information – time should be between 0 and 604800	Yes	None
Attributes	No duplicate entries	Yes	None
Location	Each return contain easting, northing, elevation information reported to nearest 0.01 meter (0.01 feet)	Yes	None
RGB values	All LAS files have RGB values attributed to them where applicable.	Yes	None
Delivery	LAS data must be delivered in 1/100th USGS 7.5 minute quadrangle tiles or specified in Purchase Order	Yes	None
Gaps	Check for Gaps in LAS coverage. (Already part of QC process)	Yes	None

Table 2. Quality Control for LAS Deliverables

Quality Control for Delivered Bare Earth DEMs			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Bare Earth DEM Description	Raster of ground surface, interpolated via triangulated irregular network from identified ground points.	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 83 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Vertical Datum	NAVD 88 (Geoid 12A)	Yes	None
Vertical Units	International Feet	Yes	None
Format	Esri™ 32 bit pixel depth floating point grid	Yes	None
Cell Size / Resolution	3 foot (1m if UTM projection specified)	Yes	None
Tiling	Full USGS 7.5-minute quadrangle (7.5 minute by 7.5 minute) tiles, unless otherwise specified in a purchase order	Yes	None
Attributes	No duplicate entries	Yes	None
Gaps	Surface Models must not have tiling artifacts or gaps at tile boundaries or artifacts such as pits, birds, striping or aliasing	Yes	None

Table 3. Quality Control for Bare Earth DEMs

Quality Control for Delivered Highest-Hit DEMs			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Highest Hit Description	Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 83 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Vertical Datum	NAVD 88 (Geoid 12A)	Yes	None
Vertical Units	International Feet	Yes	None
Format	Esri™ 32 bit pixel depth floating point grid	Yes	None
Cell Size / Resolution	3 foot (1m if UTM projection specified)	Yes	None
Tiling	Full USGS 7.5-minute quadrangle (7.5 minute by 7.5 minute) tiles, unless otherwise specified in a purchase order	Yes	None

Attributes	No duplicate entries	Yes	None
Gaps	Surface Models must not have tiling artifacts or gaps at tile boundaries or artifacts such as pits, birds, striping or aliasing	Yes	None

Table 4. Quality Control for Highest-Hit DEMs

Quality Control for Delivered Intensity Images			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Intensity Description	TIFF Raster built using returned lidar pulse intensity values gathered from highest hit returns	Yes	None
Horizontal Datum	NAD83 2011	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Units	International Feet	Yes	None
Format	GEOTIFF	Yes	None
Pixel Depth	8 bit pixel depth gray scale	Yes	16 bit pixel depth – better than required
Cell Size (X, Y)	1.5 foot (1m if UTM projection specified)	Yes	none
Normalized	Intensity shall have been normalized if the sensor or combination of sensors used on the project allow.	Yes	None
Attributes	Intensity file structure conforms to full USGS 7.5 minute quadrangle (7.5 minute by 7.5 minute) tiles	Yes	None
Gaps	Deliverable tiles checked for significant gaps not covered by aerial acquisition checks and/or caused by processing	Yes	None

Table 5. Quality Control of Intensity Images

Quality Control for Supplementary Data					
Specifications	**Description**	**Format**	**Tiling**	**Projection**	**Checked on this delivery**
Ground Survey Point Shapefile	Ground Control Points used for survey calibration and assessment of absolute vertical accuracy	Esri™ Shapefile		NAD 1983 UTM Zone 11N (2011), meter	Yes

Trajectory Files	Point location measurements of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting (meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees). Measurements are collected at one second intervals.	ascii point file - (TXYZRPH)	Date and time of acquisition	NAD 1983 UTM Zone 11N (2011), meter	Yes
Trajectory Shapefile	Trajectory data in Esri™ shapefile format attributed with project name and date of acquisition for each flight line	Esri™ Shapefile		NAD 1983 UTM Zone 11N (2011), meter	Yes
7.5 minute Quadrangle	Geometry file depicting the geospatial area associated with deliverables.	Esri™ Shapefile	Full USGS 7.5 minute quadrangle	NAD 1983 Oregon Statewide Lambert Conformal Conic (2011), Intl. Feet	Yes
0.75 minute 1/100th quadrangle	Geometry file depicting the geospatial area associated with deliverables.	Esri™ Shapefile	1/100th USGS 7.5 minute quadrangle	NAD 1983 Oregon Statewide Lambert Conformal Conic (2011), Intl. Feet	Yes
TerraSolid Processing Bins	DGN file that contains processing bins for all LAS files	DXF or DGN file	1/100th USGS 7.5 minute quadrangle	NAD 1983 Oregon Statewide Lambert Conformal Conic (2011), Intl. Feet	Yes
Delivery Area Shapefile	Geometry file depicting the geospatial area associated with deliverables.	Esri™ Shapefile	Alaska State Plane NAD 83	NAD 1983 Oregon Statewide Lambert Conformal Conic (2011), Intl. Feet	Yes

Table 6. Quality Control for Supplementary Data

Quality Control of the Report of Survey			
Specifications	**Description**	**Checked on this delivery**	**Comment**
Project Overview	Acquisition information that includes location map, project area, total area flown, acquisition dates and specified coordinate system and datum	Yes	Yes
Aerial Acquisition	Acquisition parameters including information about the aircraft, sensor, flight elevation and a map of flight line trajectories showing dates of collection	Yes	Yes
Report of Ground Survey	A detailed description of GPS procedures used in establishing the reference network and control points for the project. Includes a reference map and table	Yes	Yes

	showing monuments used and the location of all GCPs collected.		
Calibration Report	A report for the systems used in the data acquisition	Yes	More information needed
Relative Accuracy Assessment	Relative accuracy refers to the internal consistency of the data set and is measured as the differential between lidar points collected from different flight lines. Data should be presented as summary statistics and histogram form based on the entire study area.	Yes	Yes
Vertical Accuracy Assessment	Vertical accuracy shall be reported to meet the guidelines of the National Standard for Spatial Data Accuracy (Federal Geographic Data Committee (FGDC), 1998) and ASPRS Guidelines for Vertical Accuracy Reporting for Lidar Data V1.0 (American Society for Photogrammetry and Remote Sensing (ASPRS), 2004). Data shall be presented as both summary statistics and in histogram form.	Yes	Yes
Pulse Density Assessment	Contractor's assessment of pulse density over the project area, including maps showing design pulse density and ground return densities by quarter-quadrangle and histograms of both density parameters.	Yes	Yes
Summary Table	Table of deliverables, listing file formats and total number and data volume of each deliverable.	Yes	Table of deliverables not listed

Table 7. Quality Control of the Report of Survey

Spot Diameter Analysis

Horizontal accuracy is not specified in the price agreement since true horizontal accuracy is regarded as a product of the lidar spot diameter (SD). The lidar spot diameter is the area of ground that is intersected by a single pulse from the lidar sensor. SD is a function of range and beam divergence. The range is calculated as the distance between the laser aperture and the detected surface. The reported range value is given as above ground level flying height (AGL) of the sensor during collection. Beam divergence (γ) is the degree by which the light pulse emitted from the sensor fans out from a straight line. Beam divergence is measured in radians, with 1 radian = 57.3 degrees. The lidar SD is calculated by multiplying AGL and beam divergence, SD = AGL * γ

OLC Canyon Creek 2016 data was collected using a Leica ALS80 lidar sensor flown at 1500 meters AGL. The Leica ALS80 specification sheet reports a beam divergence value of 0.20 to 0.26 milliradians @ $1/e^2$, meaning that ~85% of the laser energy falls within this divergence. The range of spot diameters for the OLC Canyon Creek 2016 project is between 0.300 meters and 0.390 meters. This equals an average spot diameter of 0.345 meters for these deliveries, which is within the project specification tolerance of 0.15 meter to 0.40 meter for spot diameter.

Swath-to-Swath Consistency Analysis

DOGAMI has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between flight lines. DOGAMI measures consistency offsets throughout delivered datasets to ensure that project specifications are met.

Consistency refers to lidar elevation differences between overlapping flight lines. Consistency errors are created by poor lidar system calibration settings associated with sensor platform mounting. Errors in consistency manifest as vertical offsets between individual flight lines. Consistency offsets were measured using the "Find Match" tool within the TerraMatch© software toolset. This tool uses aircraft trajectory information linked to the lidar point cloud to quantify flight line-to-flight line offsets.

To quantify the magnitude of this error, 596 out of 596 delivered data tiles (100%) were examined for vertical offset between flight lines. Data tiles with less than 1000 points were not used in analysis. Each tile measured 750 x 750 meters in size (Figure 4). The average number of points used for flight line comparison was 32,754,860 per tile (Table 8a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meter in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. 182 flight lines out of 189 total flight lines (96%) were sampled and compared for consistency.

Results of the consistency analysis found the average flight line offset to be 0.03 meters (0.11 feet) with a maximum error of 0.06 meters (0.19 feet) (Table 8b). Distribution of error showed 98% of all error was less than 0.055 meters (0.180 feet) and 100% less than 0.0575m (0.188 feet) (Figure 4 and 5). These results show that all data are within specification.

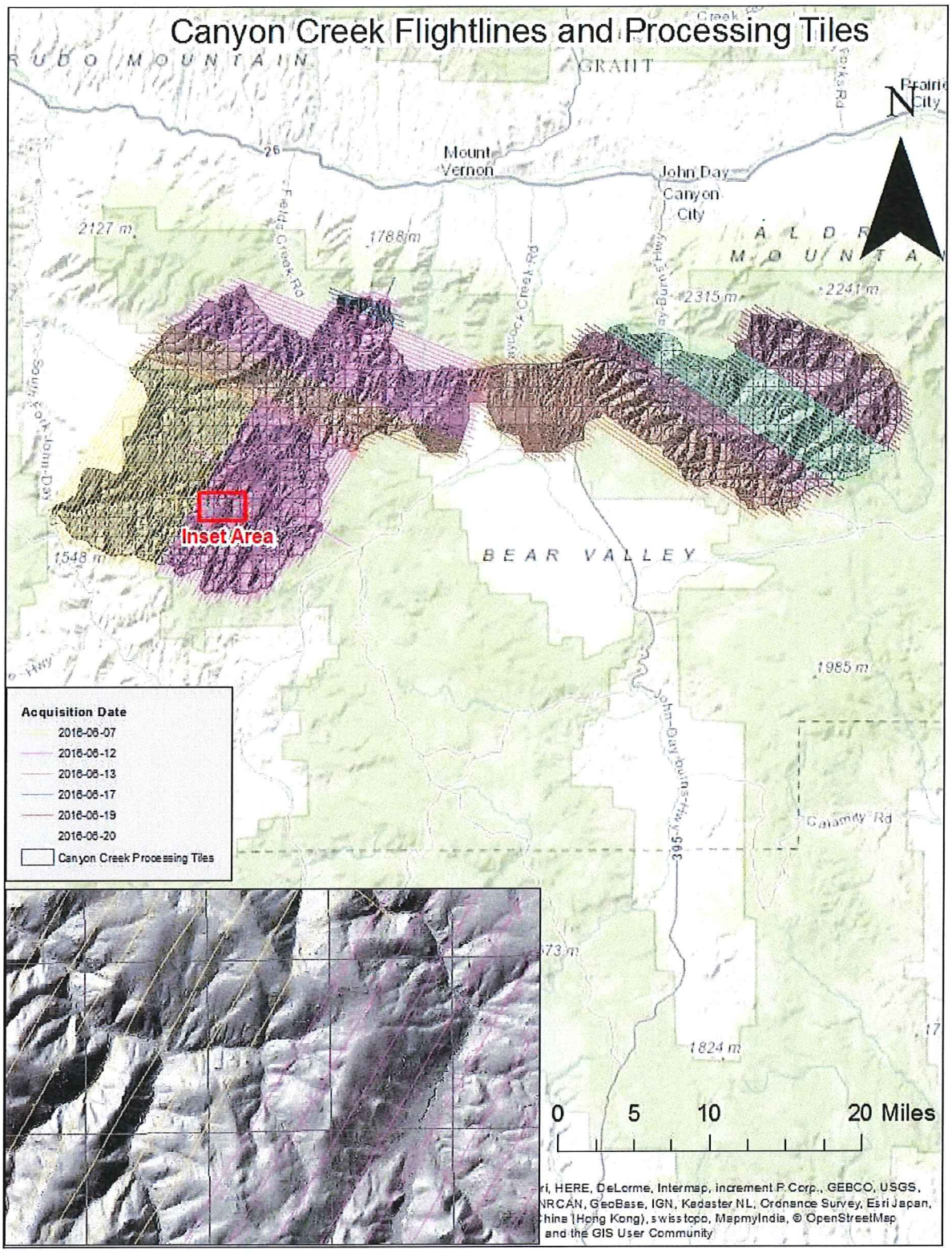

Figure 3. Spatial distribution of flight lines and processing tiles used in the consistency analysis.

Table 8a. Summary Results of Consistency Analysis

Summary Statistics	
# of Tiles	596
# of Flight Line Sections	182
Avg. # of Points	32,754,860
Avg. Magnitude Z error	0.03 meters

Table 8b. Descriptive Statistics for Magnitude Z Error.

Descriptive Statistics	Meters	Feet
Mean	0.03	0.11
Standard Error	0.00	0.00
Standard Deviation	0.01	0.02
Sample Variance	0.00	0.00
Range	0.04	0.12
Minimum	0.02	0.06
Maximum	0.06	0.19

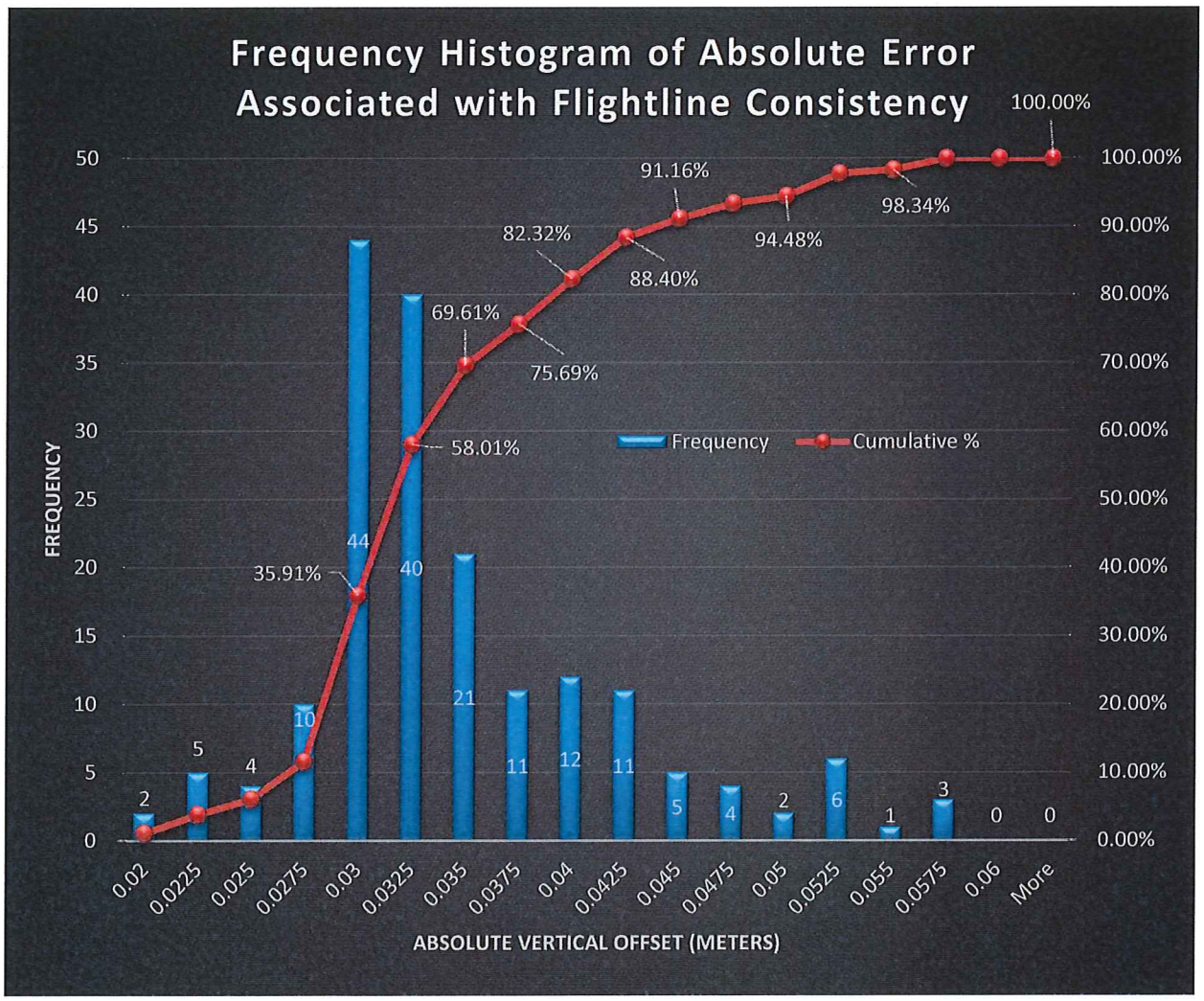

Figure 4. Flight line Consistency Histogram in meters

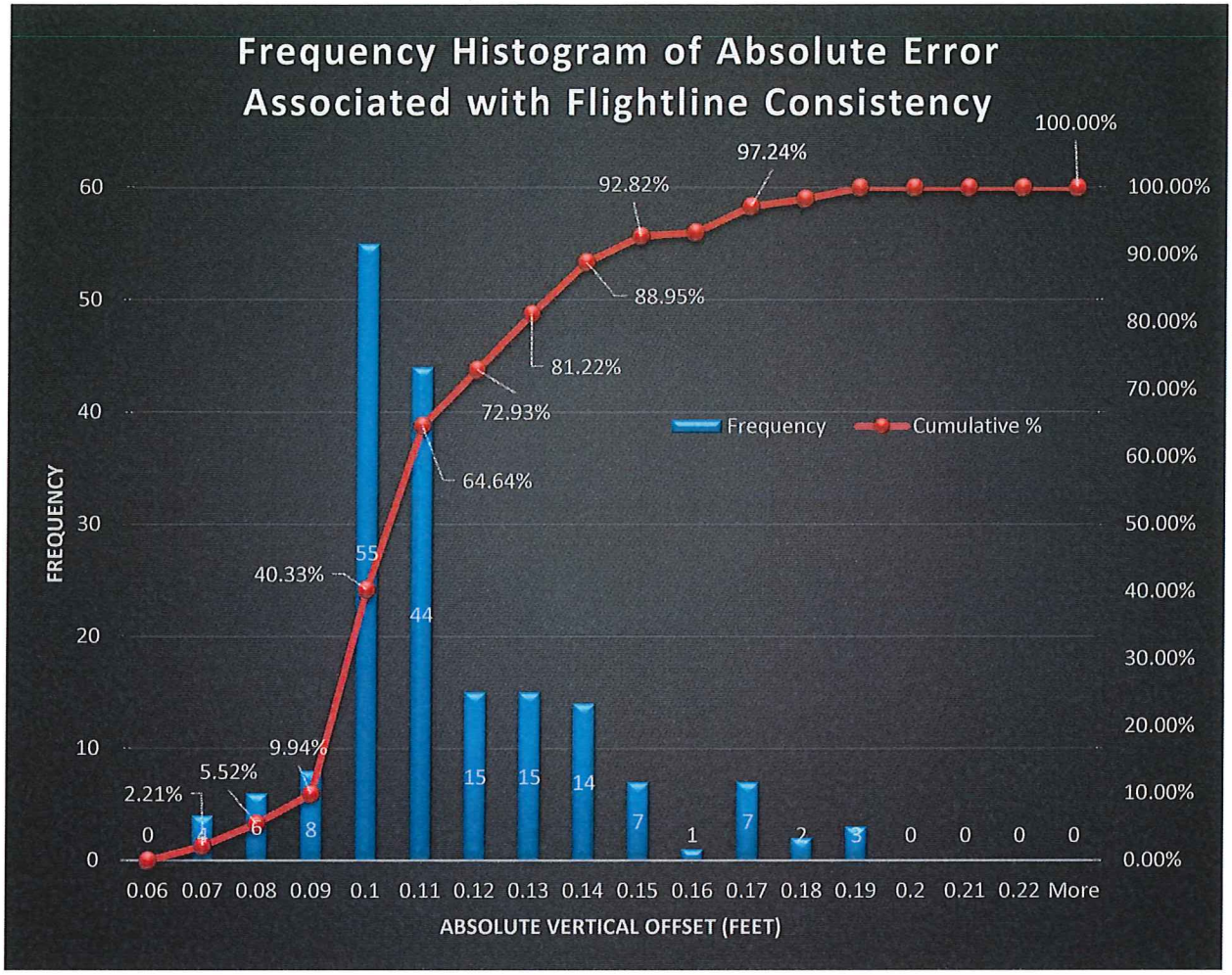

Figure 5. Flight line Consistency Histogram in feet

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS™ software for visual analysis. Data were examined through slope and hillshade models of bare-earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 6). Both bare-earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 7), seam line offsets, pits (Figure 8), and birds.

Calibration offsets typically are visualized as a corduroy-like pattern within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (Figure 7). Seam line offsets

occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 8). Birds (high points) typically occur where the laser comes into contact with atmospherics[1].

During visual analysis of OLC Canyon Creek 2016 raster data, 80 observed errors were digitized for spatial reference and stored in Esri™ shapefile format. Each feature was assigned an ID value and included a brief description of the observed error. The shapefile was then delivered to the vendor for locating and fixing errors. Upon receiving the observed error locations, the vendor performed an analysis to conclude whether the error was valid and provided comments on how the data was adjusted. 80 out of the 80 observed errors (100%) were adjusted and the data was reprocessed to accommodate fixes. Errors that were not fixed by the vendor were reviewed by DOGAMI staff to ensure justification was valid. Final sets of lidar 3ft grids were loaded into ArcGIS™ software and examined to ensure edits were made and visually inspected an additional time for completeness (Figure 9).

[1]Atmospherics include clouds, rain, fog, or virga

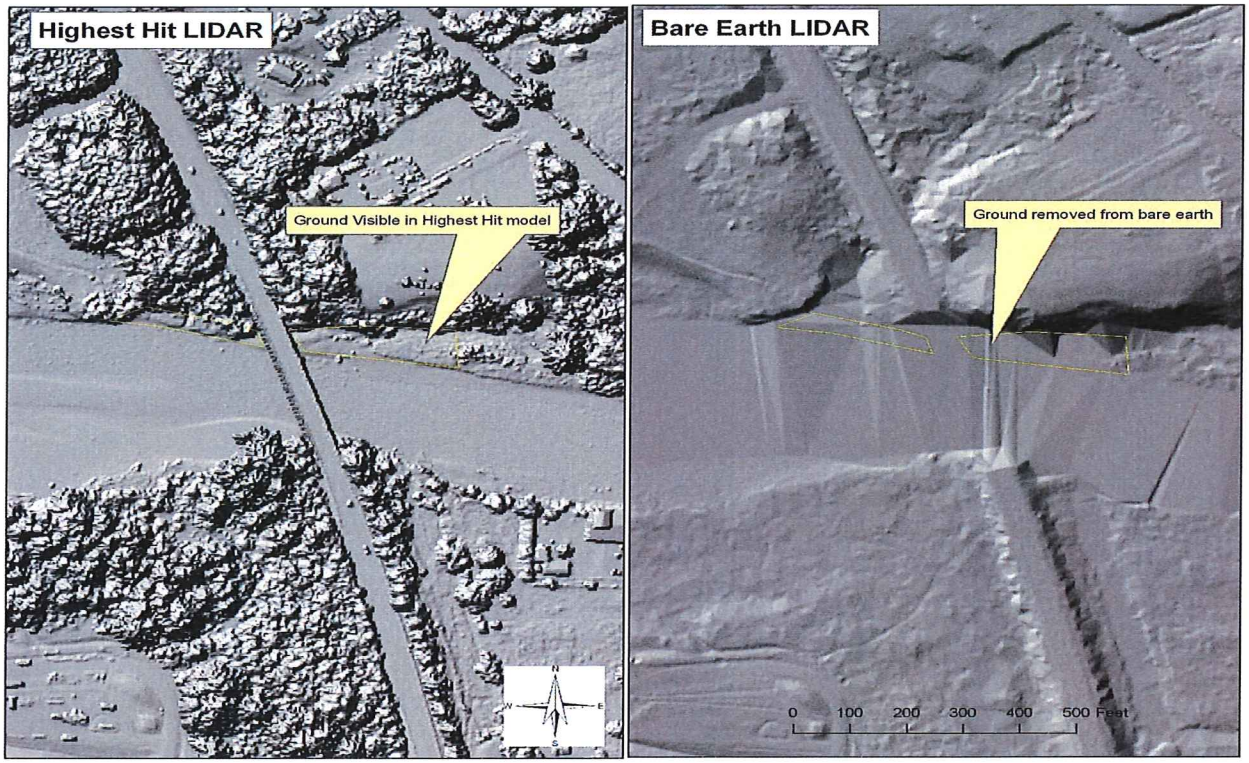

Figure 6. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features

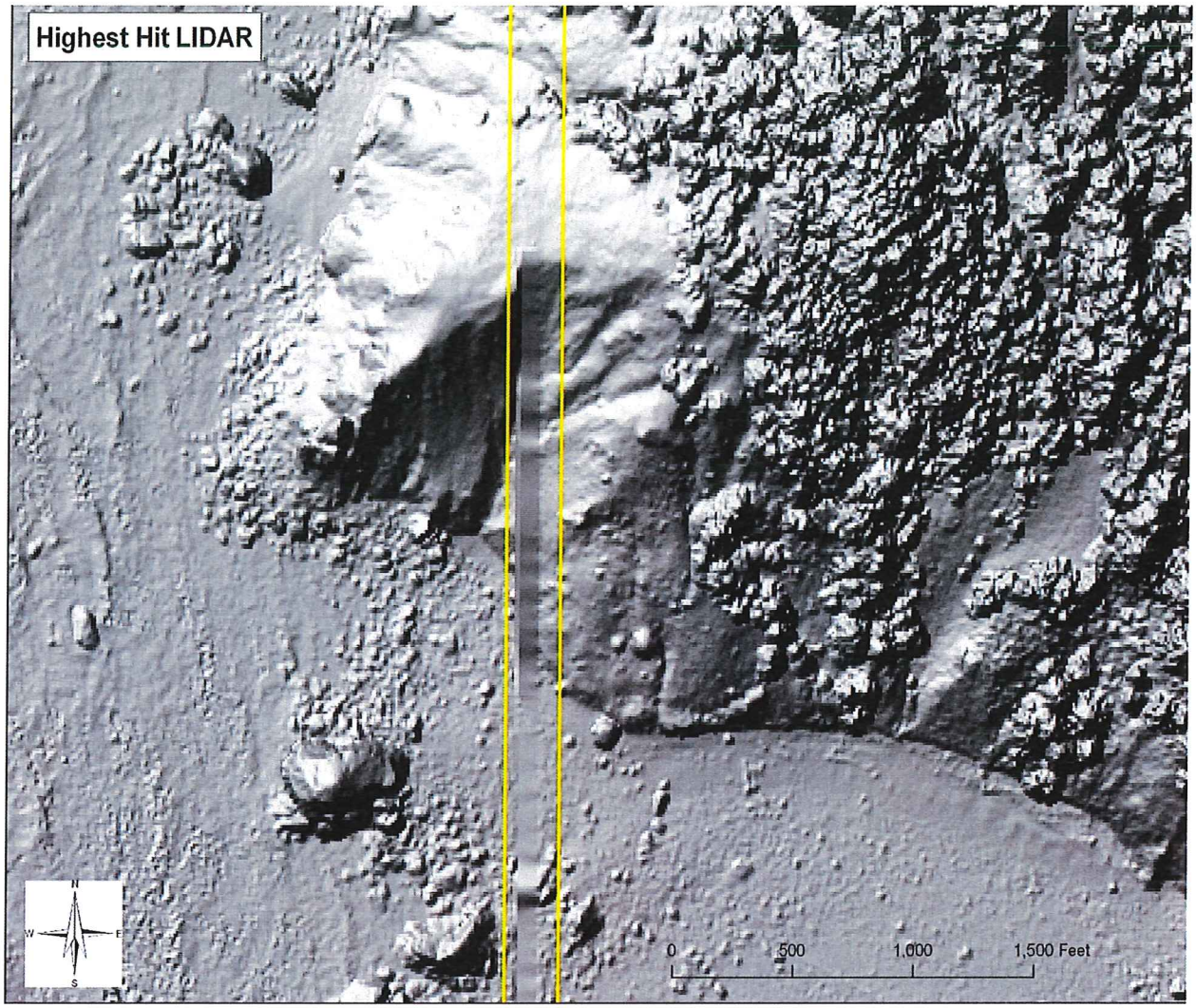

Figure 7. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

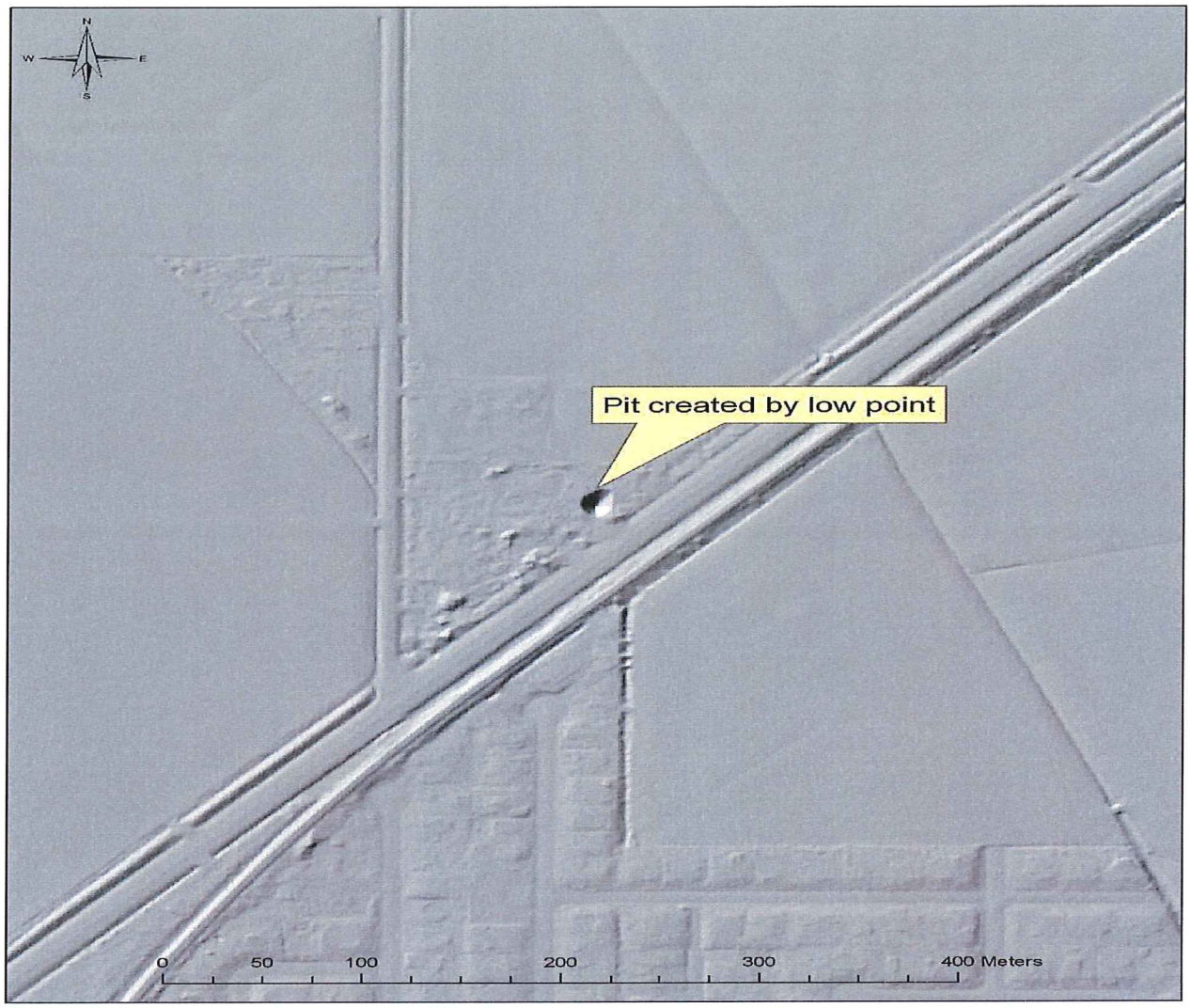

Figure 8. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point elevation is assigned to the grid value.

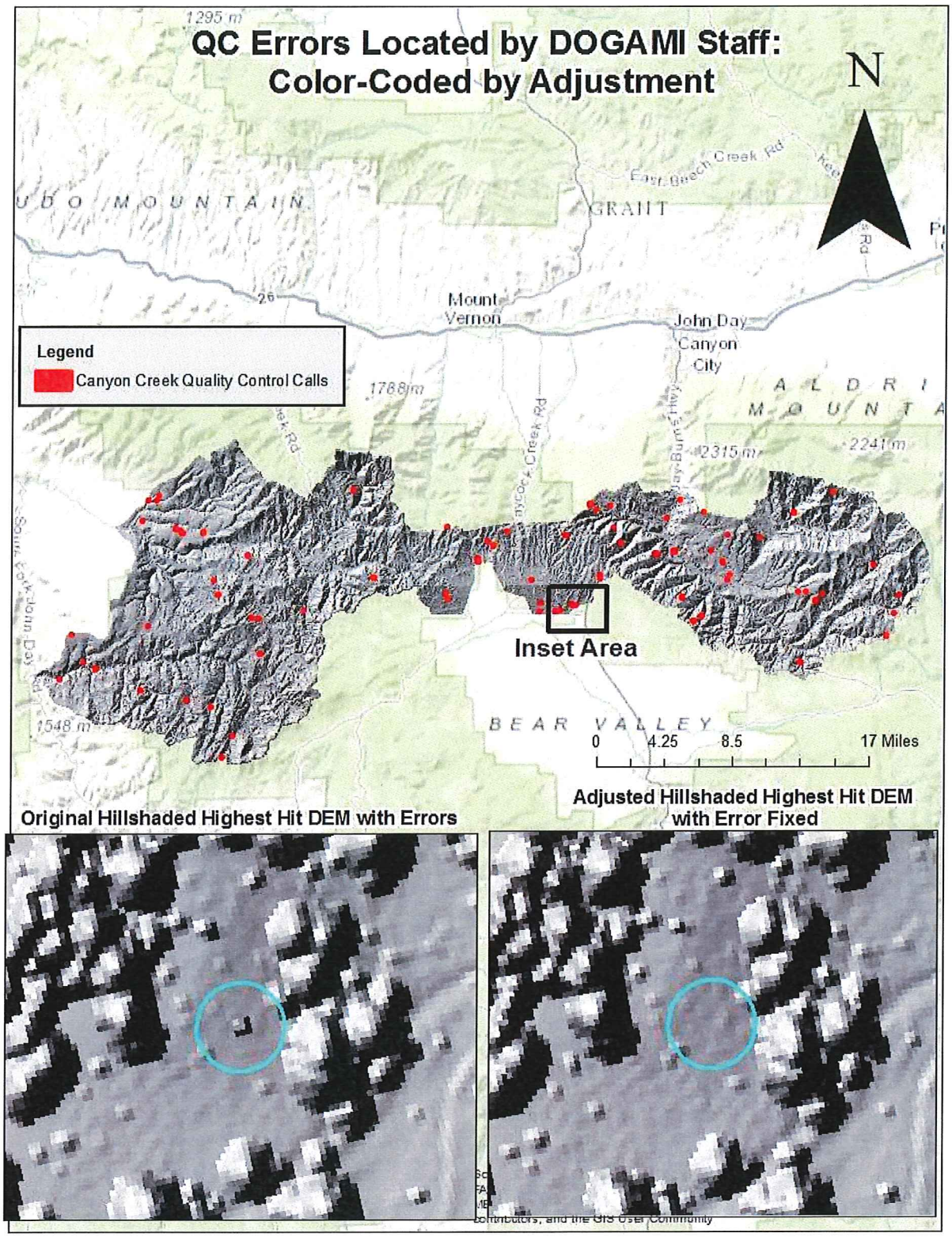

Figure 9. Spatial distribution of visual QC errors located by DOGAMI staff.

Absolute Accuracy Analysis

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used two Trimble™ R10 GNSS Systems, and an optional Trimmark™ 3 radio (Figure 10) to measure GCP's for the Canyon Creek 2016 project area. One Trimble™ R10 GNSS Systems was mounted on a fixed height (typically 1.8 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. The second R10 GNSS System, referred to as the "rover" unit is then attached to a fixed height survey pole for static point measurements within the project boundaries. In areas of flat terrain and limited tree cover, the rover unit will use a truck mount on the side of a vehicle to collect continuous RTK points along hard surfaces. Utilizing both single point and continuous RTK collection allows for GCP collection in various terrain and topography as well as provide a density of GCPs on hard surfaces for accurate reporting of absolute accuracy. The Trimmark™ 3 radio is used in areas of high relief in order to extend the range of the R10 internal radio broadcast. The Trimble™ R10 GNSS Systems typically have a broadcast range of 3 miles without the Trimmark™ 3 radio.

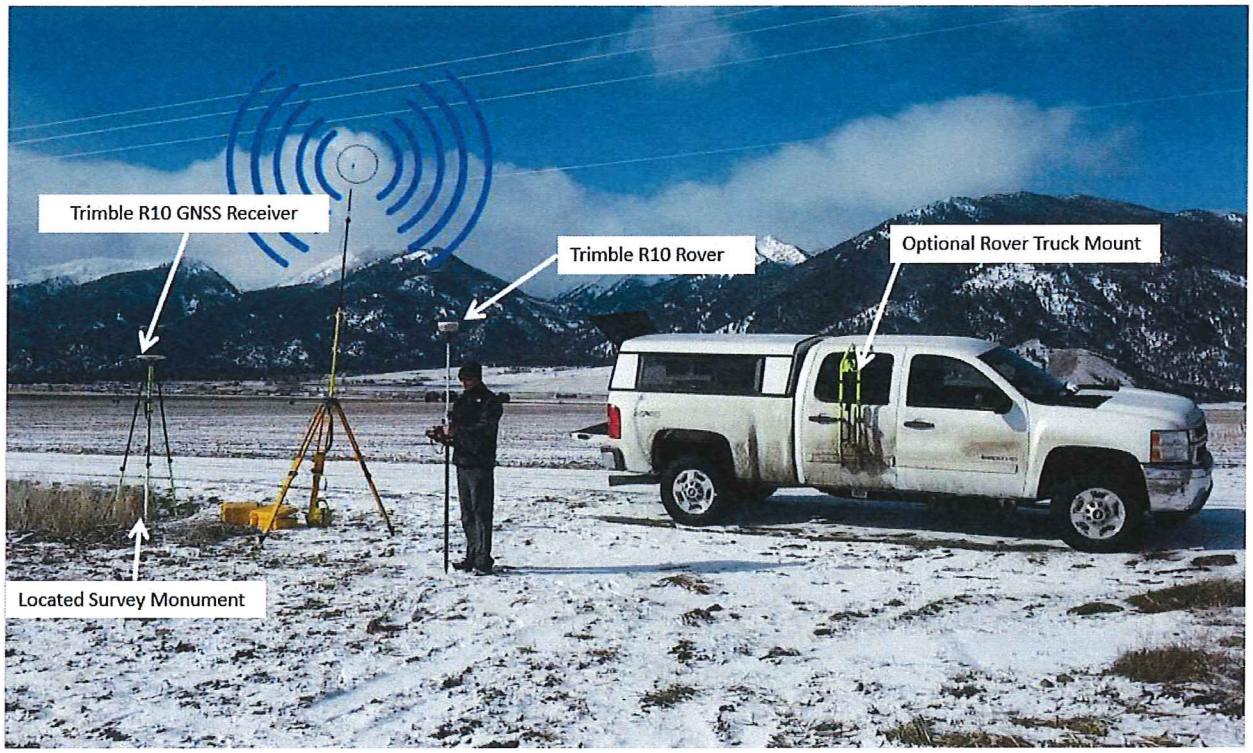

Figure 10. The Trimble R10 base station antenna located over a known reference point outside Baker City. Corrected GPS position and elevation information is then transmitted either by Internal Radio or by a Trimmark III base radio to the R10 GPS rover unit.

The approach adopted for DOGAMI lidar surveys was comprised of four components:

1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected ephemeris data is then submitted to the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.
2) Collect GCP's in vegetative and non-vegetative land cover within the project area. Vegetative land cover GCP collection is typically achieved through static point collection. Non-vegetative point collection is typically achieved through continuous RTK collection along relatively flat surfaces (roads, paths, parking lots etc.).
3) Post-process collected GCP points in Trimble Business Center. GCPs collected in the field are filtered to remove points that have horizontal and vertical precisions less than 0.03m. GCPs points that have a high Point Dilution of Precision (PDOP) are also removed sine high PDOP values affect horizontal and vertical precision. GCPs that have been filtered for accuracy are then exported out to TBC.
4) GCPs elevation values are compared to the lidar derived Bare-Earth raster elevations. Statistical information on the offsets between GCPs and the Bare-Earth rasters is calculated and analyzed by DOGAMI staff.

After collecting the GCP data in the field, the GPS data was post-processed using Trimble Business Center software. Data post-processing typically involved calibrations against at least three CORS stations as well as from local site calibrations performed in the field using those benchmarks that had been independently verified. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the R10 GNSS System have horizontal errors of approximately ±1-cm + 1ppm (parts per million * the baseline length) and ±2-cm in the vertical (Trimble Navigation System, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties. Data is post processed to refine measurements so that horizontal and vertical errors are less than 0.03 meters (0.065 feet). GCPs with Point Dilution of Precision (PDOP) values higher than 3.0 are not used for comparison. High PDOP values reduce the horizontal and vertical precision of collected GCPs, which is why we filter for high PDOP values.

DOGAMI collected GCP points on September 21, 2016. Ground conditions were good every day of collection with no snow and no inclement weather on either collection dates. The base stations used in the GCP data collection for OLC Canyon Creek 2016 was located on monuments Canyon Creek 01 and FOX_CX3 which were established by the vendor (See Report of Survey). Accuracy assessments of survey monuments are provided in the form of an OPUS solution from NGS, below is the OPUS solution for monument FOX_CX3.

```
NAV FILE: brdc2650.16n              OBS USED: 4088 / 4600  : 89%
 ANT NAME: TRMR10        NONE        QUALITY IND. 36.67/ 71.16
ARP HEIGHT: 2.3516563387307         NORMALIZED RMS:      0.271
```

REF FRAME: NAD_83(2011)(EPOCH:2010.0000) IGS08 (EPOCH:2016.72353)

X:	-2242005.609(m)	0.013(m)	-2242006.511(m)	0.013(m)
Y:	-3992819.951(m)	0.016(m)	-3992818.721(m)	0.016(m)
Z:	4426890.248(m)	0.021(m)	4426890.226(m)	0.021(m)

LAT:	44 13 23.94969	0.004(m)	44 13 23.96343	0.004(m)
E LON:	240 41 7.38069	0.007(m)	240 41 7.31814	0.007(m)
W LON:	119 18 52.61931	0.007(m)	119 18 52.68186	0.007(m)
EL HGT:	1408.796(m)	0.028(m)	1408.329(m)	0.028(m)
ORTHO HGT:	1427.096(m)	0.032(m)	[NAVD88 (Computed using GEOID12B)]	

	UTM COORDINATES UTM (Zone 11)	STATE PLANE COORDINATES SPC (3601 OR N)
Northing (Y) [meters]	4899282.143	62552.878
Easting (X) [meters]	315123.712	2594717.159
Convergence [degrees]	-1.61480083	0.84065742
Point Scale	1.00002037	1.00002951
Combined Factor	0.99979951	0.99980865

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vendor. The average horizontal accuracy for all monument locations occupied by DOGAMI during GCP data collection is 0.004 meters Northing and 0.007 meters Easting (Table 9). The average root mean square error (RMSE) for positional accuracy for all monument locations occupied by DOGAMI during GCP data collection is 0.271 meters.

Occupied Monuments	*meters*	feet
Avg. Northing accuracy	0.004	0.013
Avg. Easting accuracy	0.007	0.022
Avg. RMSE for positional accuracy	0.271	.889

Table 9. Average accuracy values for occupied monuments

Vertical accuracy analysis of delivered lidar data consisted of differencing collected GCP data and the lidar Digital Elevation Models (DEM) to expose offsets. These offsets were used to produce a mean vertical error and vertical RMSE value for the entire delivered data set. Project specifications list the maximum acceptable mean vertical offset to be 0.20 meters (0.65 feet) and the maximum vertical RSME to not exceed 0.0925 meters (0.303 feet).

A total of 42 measured GCP's were obtained in the OLC Canyon Creek 2016 area and were compared with the lidar elevation grids (Figure 12). The data delivered to DOGAMI was found to have a mean

vertical offset of -0.11 meters (-0.36 feet) and an RMSE value of 0.08 meters (0.29 feet). Offset values ranged from -0.18 meters (-0.61 feet) to 0.03 meters (0.10 feet) (Table 10 and Figure 13 and 14).

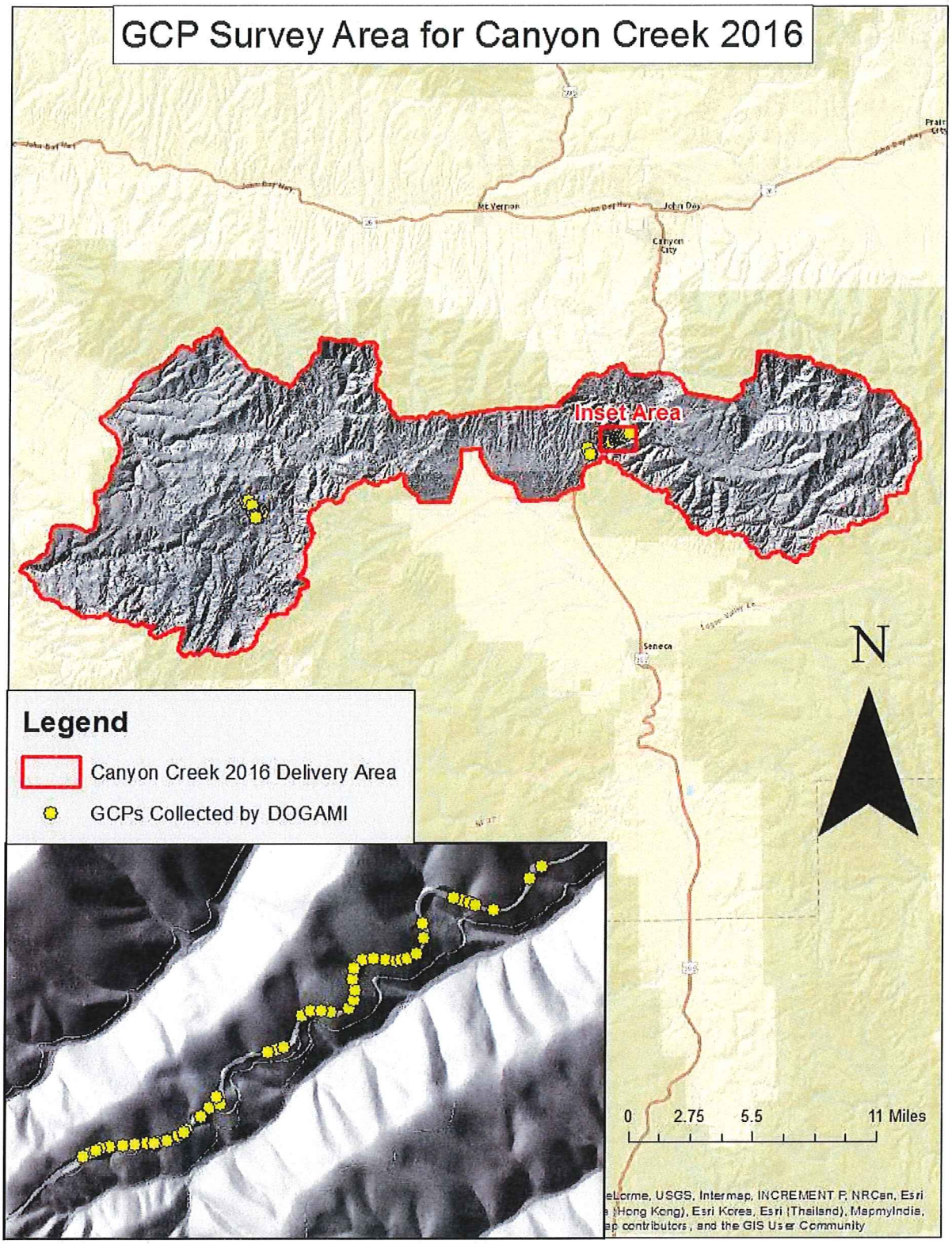

Figure 11. Locations of GCPs surveyed by DOGAMI staff. Data was used to test absolute accuracy for OLC Canyon Creek 2016 project areas.

Table 10. Descriptive Statistics for absolute value vertical offsets.

Descriptive Statistics	Meters	Feet
Mean	-0.11	-0.36
Standard Error	0.01	0.02
Standard Deviation	0.05	0.17
Range	0.21	0.71
Minimum	-0.18	-0.61
Maximum	0.03	0.10
RMSE	0.08	0.29

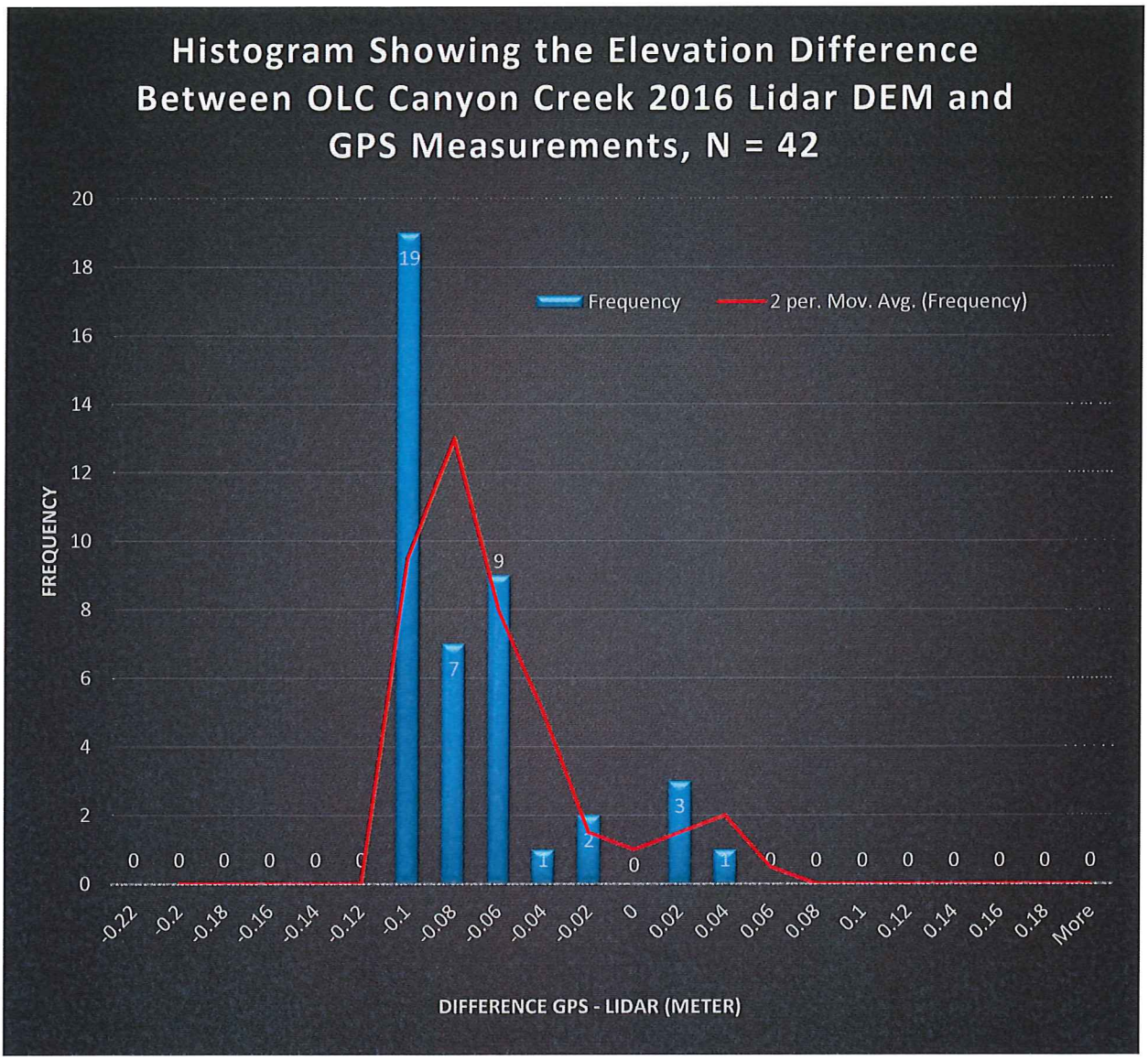

Figure 12. Histogram of absolute vertical accuracy in meters.

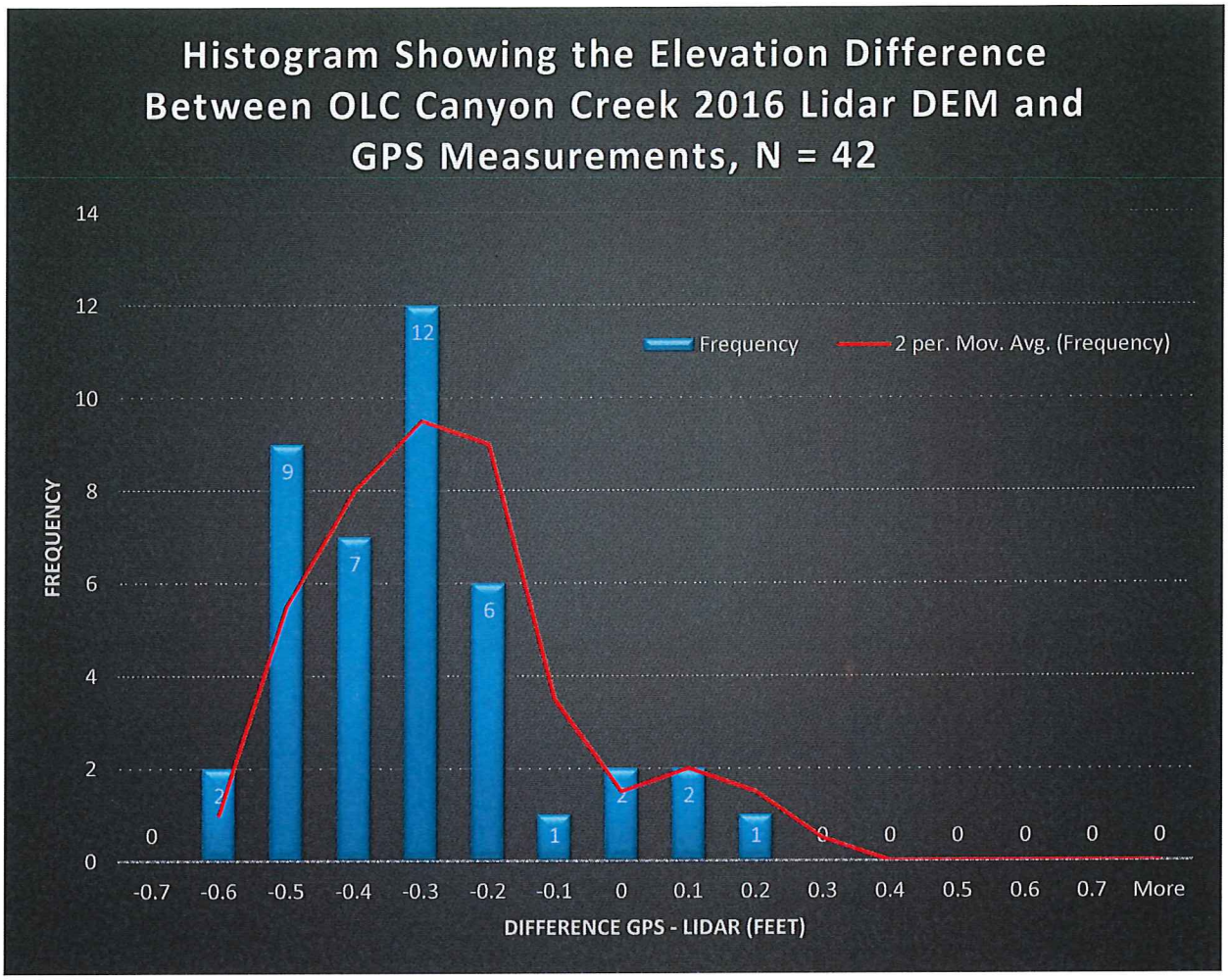

Figure 13. Histogram of absolute vertical accuracy in feet.

Pulse Density

DOGAMI has specified that the aggregate design multi-swath pulse density for the OLC Canyon Creek 2016 project must be 8.0 pulses per square meter (m^2) or higher. Pulse density is calculated as the number of pulses per unit area, commonly measured as pulses per m^2. This calculation is based on the number of first return pulses divided by the area of the tile.

The all-return LAS points are comprised of multiple returns from each laser pulse. These multiple returns are created when a laser pulse encounters multiple reflection surfaces as it travels toward the ground. Pulse density was measured by parsing out first-return points from the all-return LAS files. First-return points are used to assess pulse density because multiple returns from a single pulse would introduce bias into the statistics. DOGAMI staff used Bentley© Microstation software to filter the LAS point files and output new LAS files that only contain first-return points. Statistics were calculated on the newly created files using the ArcGIS 3D analyst tool called "Point File Information." This tool calculated the total number of first return points for each LAS file. Each Las file's first return point count was then compared to the size of each LAS file to determine the overall pulse per square meter. Using the 1/100th USGS 7.5 minute quadrangle extents, DOGAMI staff created polygons that graphically depict the pulse density of the project area (Figure 14).

To quantify pulse density of the OLC Canyon Creek 2016 project, 595 all-return LAS files (100%) were parsed into first-return point files and compared to their data extents. Results of the pulse density analysis found the average pulse density to be 10.6 pulses per m^2 (Table 11). Certain types of surfaces (dense vegetation, water) may return fewer pulses than the laser originally emitted; therefore density values can vary according to terrain and land cover. Pulse densities for OLC Canyon Creek 2016 LAS tiles ranged from 4.6 pulses per m^2 to 31.1 pulses per m^2. 574 LAS tiles out of 595 (96%) have a pulse density of ≥ 8.00 pulses per m^2 (Figure 15). These results show that all data are within tolerances of pulse density according to the contract agreement.

Summary Statistics	*Pulses per m^2*
Mean	10.64
Standard Error	0.10
Standard Deviation	2.67
Sample Variance	7.16
Range	26.46
Minimum	4.62
Maximum	31.09

Table 11. Summary Results of Pulse Density Analysis

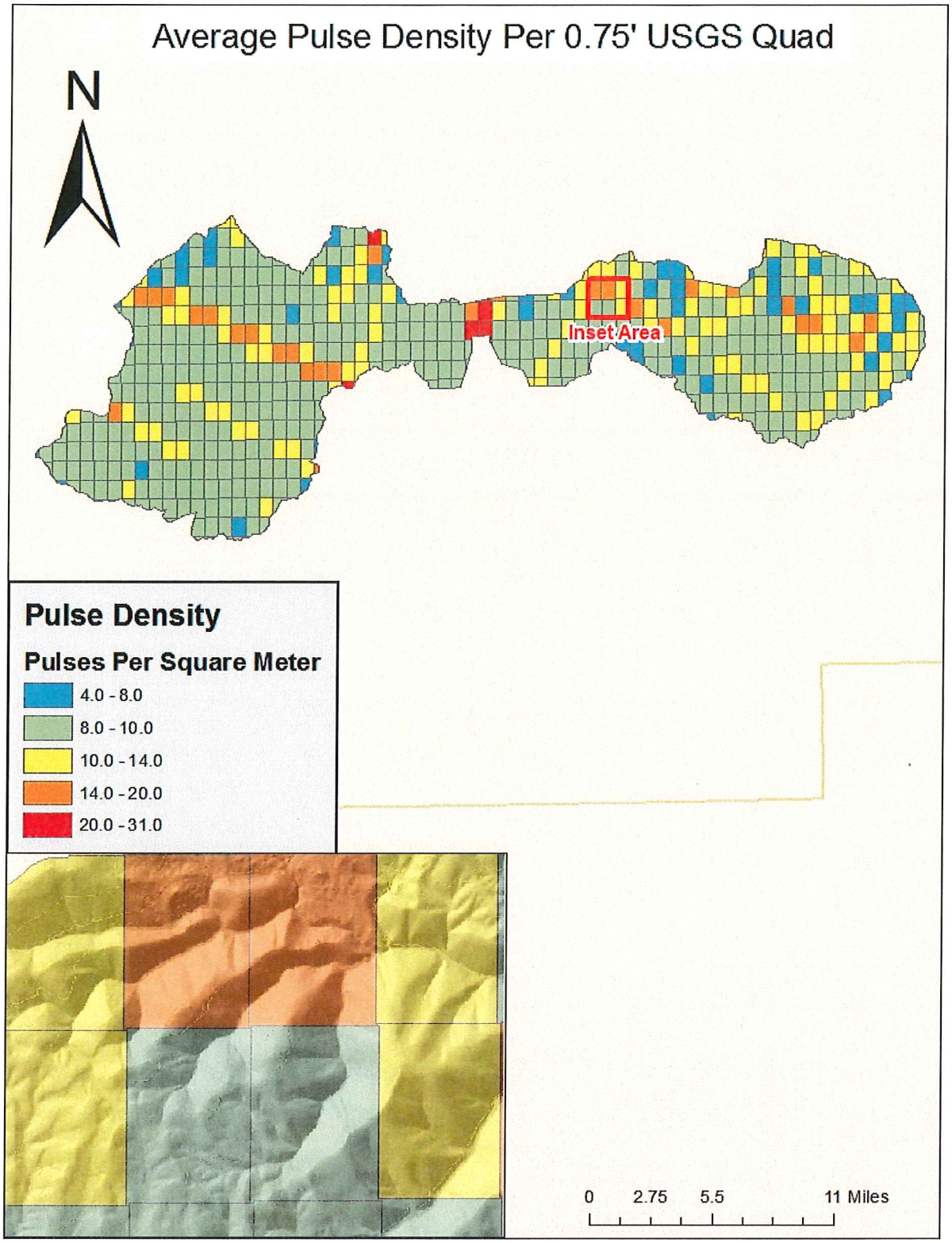

Figure 14. Pulse Density of 1/100th USGS 7.5 minute quadrangle LAS tiles.

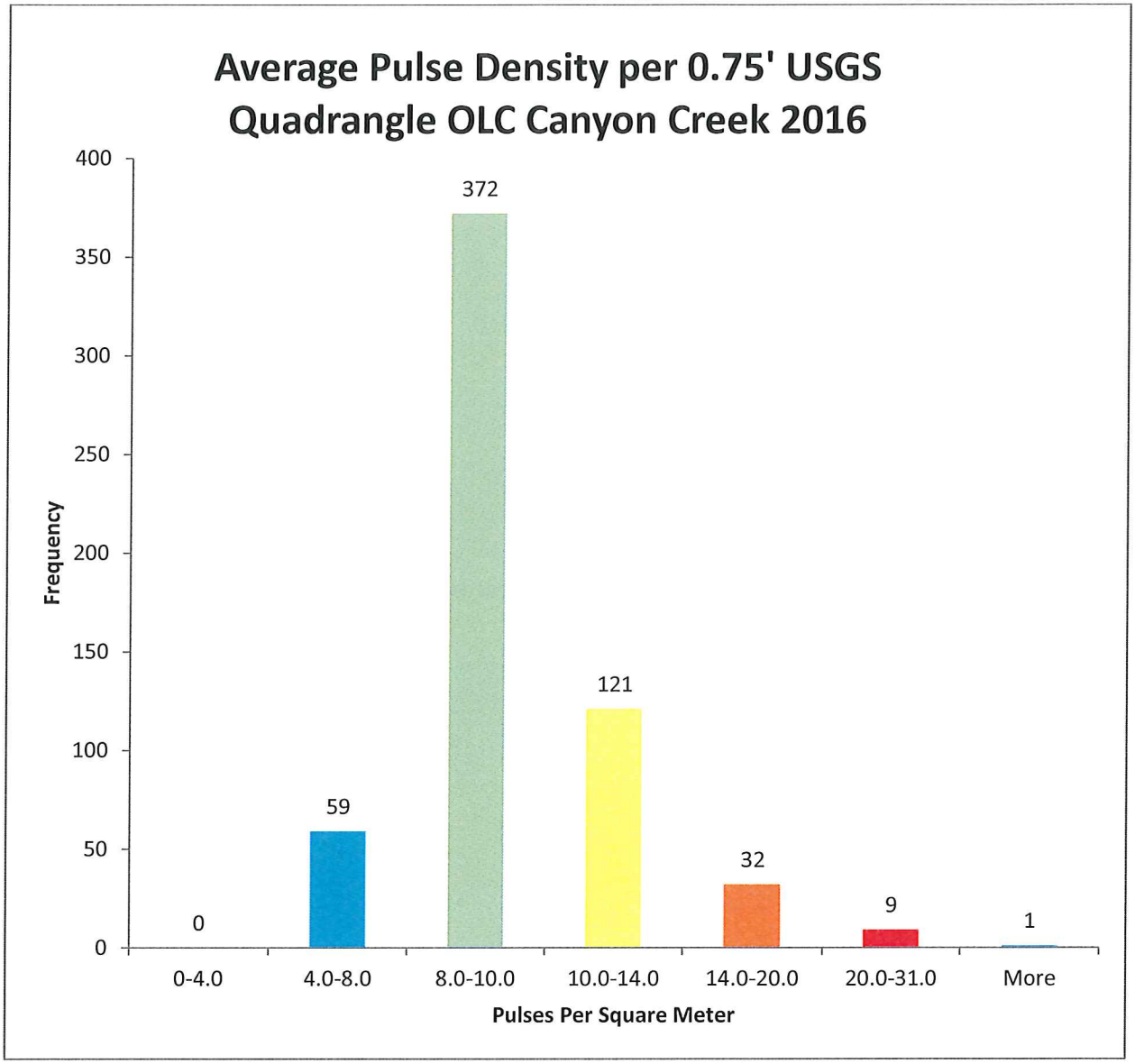

Figure 15. Histogram of Average Pulse Densities for Canyon Creek 2016.

Metadata Analysis

Metadata analysis compared the structure of the metadata file against FGDC standards. Metadata content was reviewed by using a visual check in Esri™ ArcCatalog. No structure issues were found when validating the compliance of metadata to FGDC standards.

Acceptance

The data described in this report meet and exceed project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of December 29, 2016. Quality control has confirmed that all delivered data is within specification and function correctly. Quality Control has evaluated acquisition parameters to confirm that data was collected within project design scope. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in the agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement. Pulse density has been analyzed through the project area and the aggregate pulse density is greater than 8.0 pulse per square meter.

Approval Signatures

_____ Date: 1/30/17

Jacob Edwards
Lidar Database Coordinator – Department of Geology & Mineral Industries